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Flexible Fiber reinforced link slabs used as continuous expansion joints in bridge decks

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Introduction

Deterioration of bridge structures with mechanical expansion joints between simply supported spans can require repeated maintenance and high repair costs (Figure 1). The focus of the work presented was to design and construct a prefabricated link slab element to be positioned as a joint between two adjacent bridge deck spans. In the proposed system, a ductile cement-based composite section reinforced with Glass Fiber Reinforced Polymers (GFRP) is suggested as a replacement for conventional mechanical expansion joints.

Figure 1: Example of currently used mechanical expansion joints

The combination of this ductile concrete together with corrosion resistant GFRP reinforcement serves as a flexible deformation element between the adjacent bridge deck segments (Figure 2). The use of an Engineered Cementitious Composite (ECC) material instead of conventional concrete significantly reduces crack widths under service conditions and prevents deterioration of the link slab during repeated deformation cycles. By utilizing composite materials such as ECC and GFRP, the aim of this study was to improve the performance as well as the production process and applicability of currently used mechanical expansion joints.

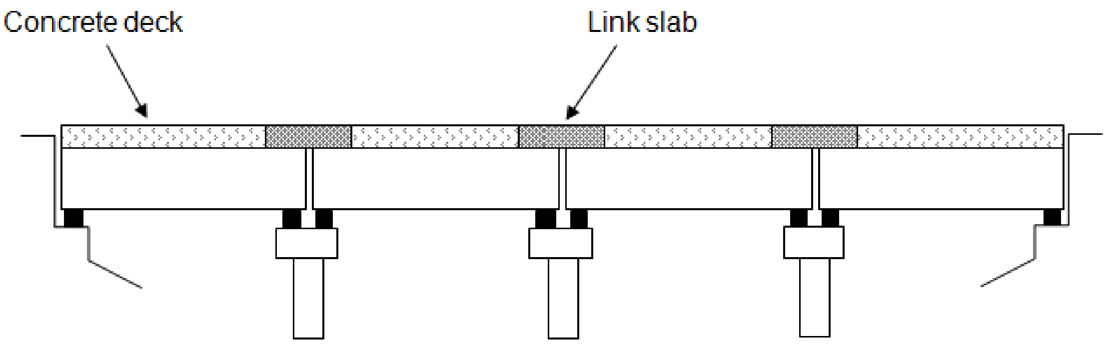

Figure 2: Schematic illustration of a link slab in a bridge structure

Experimental program

A full scale prefabricated link slab cast into a representative bridge joint configuration was prepared and tested. The GFRP reinforced ECC link slab was 6 ft 6 in (2 m) long, 3 ft 3 in (1 m) wide and 3 inch (75 mm) thick with ten GFRP rebars of 1/4 inch diameter, resulting in a reinforcement ratio of $\rho = 0.41$ %.

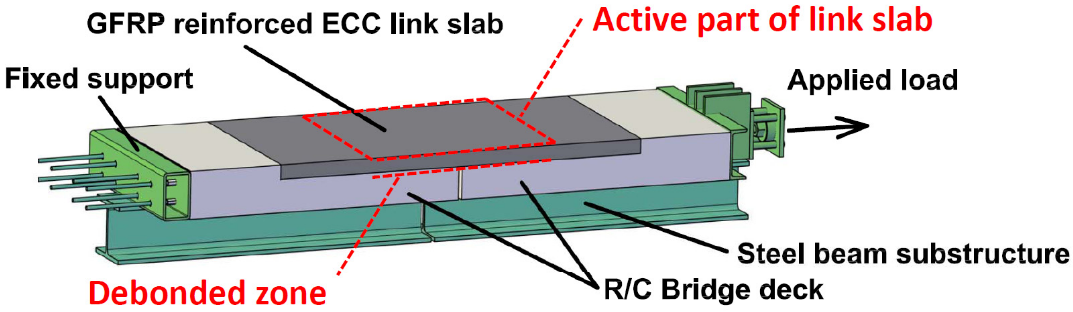

Figure 3: Illustration of test configuration

The active part of the link slab in the 3 ft 3 in (1 m) center section was designed with a de-bonding layer at the interface to the existing reinforced concrete deck of the bridge to allow unrestrained deformations to take place in the de-bonded part of the link slab. The deformations in the link slab were induced by applying a tensile load to the structure. A non-contact high resolution photogrammetric analysis system was employed to monitor the crack formation and development on the top surface of the link slab during testing.

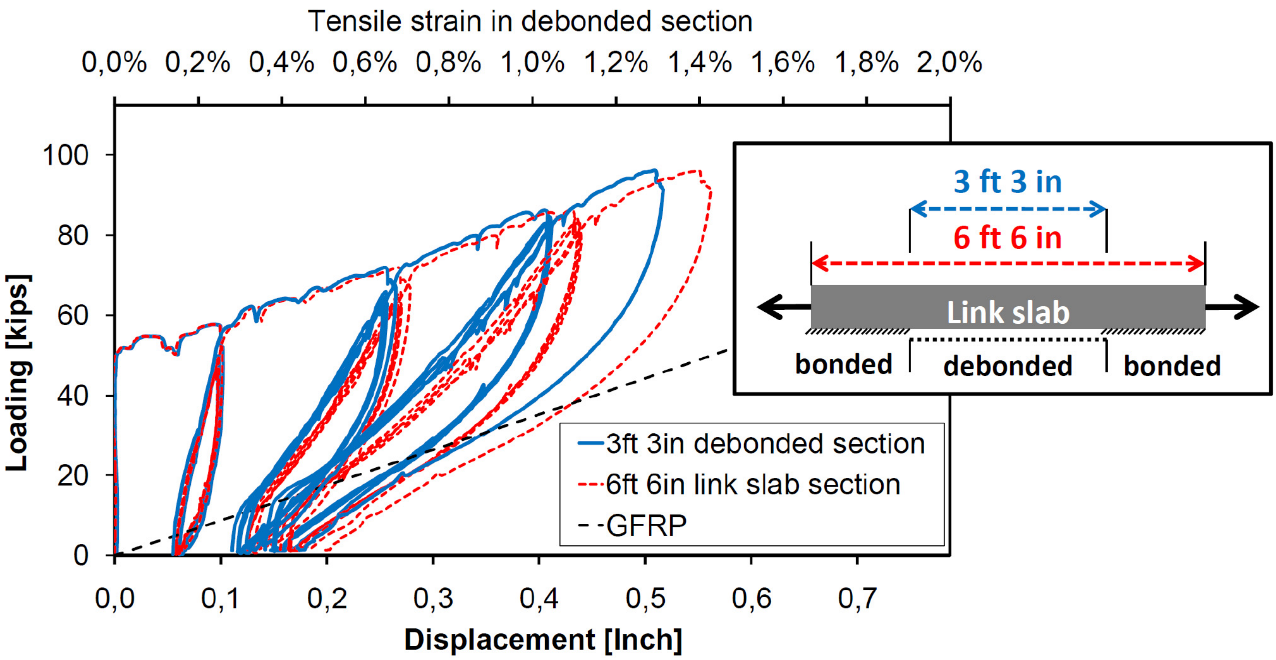

Figure 4: Load – displacement response of a link slab in direct tension.

The structural response of the link slab during four tensile loading sequences to displacements of: 0.1 , 0.25 , 0.4 and finally 0.5 inch measured over the 3 ft 3 in center section. For each of the four loading stages, a number of loading and unloading repetitions were applied. Furthermore, the elongation at the middle section is compared to the total elongation of the entire link slab (including the bonded and de-bonded section) and the displacements of the adjacent bridge spans. Results show a 0.04 inch deformation difference between the 3 ft 3 in de-bonded section and the 6 ft 6 in total link slab length, indicating that nearly all of the total deformation takes place at the active part of the link slab.

The elastic response of the link slab reaches about 52 kips, equivalent to a nominal stress in the cross-section of approximately 0.44 ksi before the ECC matrix starts forming cracks. All subsequent loading sequences converge in a path that is slightly stiffer than that of the GFRP alone. The residual tensile deformation in the link slab after complete unloading was measured to be 0.17 inch over the de-bonded section, or about 35 % of the 0.5 inch elongation previously reached.

During all loading sequences, the crack formation and development was monitored. Crack openings ranged from 0.002 in to 0.018 in with an average value of 0.008 when reaching the maximum induced tensile displacement of 0.5 in in the de-bonded section (1.3 % tensile strain). Furthermore, results show that new cracks initiate in the link slab up to 0.25 inch tensile displacement. Beyond which the existing cracks increase their opening.

The increase in the tension stiffening effect of the ECC link slab during the loading sequences (Figure 4) indicates that the interface between the rebar and the surrounding matrix is intact and is effectively transferring forces between the matrix and rebar. This is due to the formation of multiple cracks in the matrix and corresponding fiber bridging in the cracked ECC, which allows for an evenly distributed load transfer between the rebar-matrix interface as opposed to the localized stress continuation observed in conventional R/C.

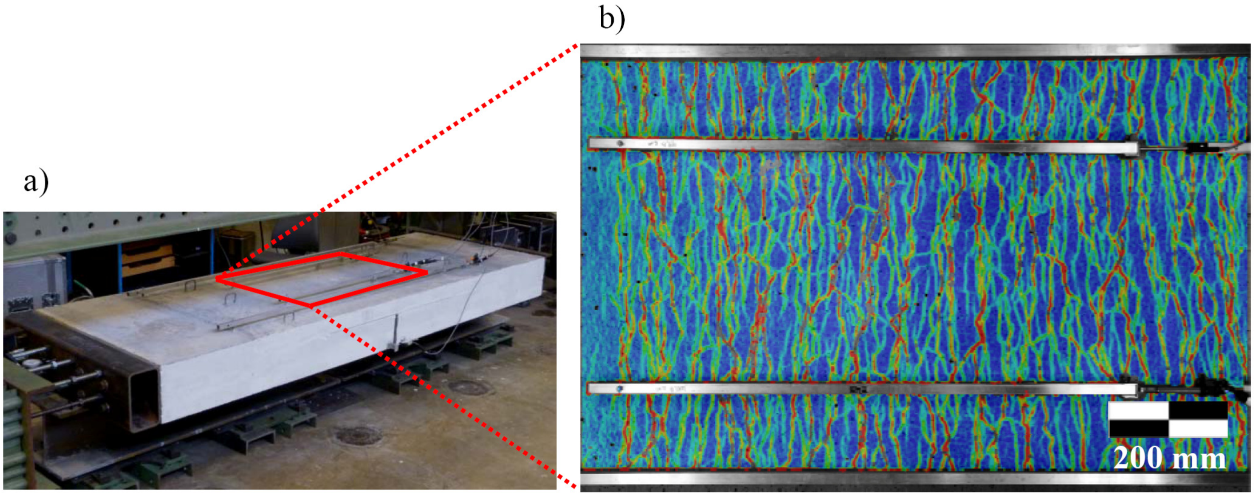

Figure 5: a) the link slab in testing setup, b) micro cracking in the link slab at 0.5 in induced displacement

This evenly distributed force transfer in the reinforced composite specimen and compatible deformation behavior results in lower localized stresses, which translates to less deterioration of the interfacial bond between the rebar and the matrix.

After crack saturation is reached at 0.25 inch displacement of the adjacent bridge decks, there appears to be no additional plastic (permanent) deformation of the 3 ft 3 in de-bonded zone of the link slab. However, after the 0.25 inch tensile displacement the development of deformations outside the de-bonded zone increases, cracking can be seen as the deformation difference between sequences 3 and 4.

The design of the ECC link slab with the de-bonded section and the load transfer zones (where additional reinforced was provided) was found to effectively distribute the imposed deformations in the adjacent bridge span section throughout the ECC link slab. Furthermore, the crack formation and development observed and analyzed on the link slab exhibited a uniform deformation.

The post-cracking behavior of ECC with its multiple cracking, limited crack widths and improved interfacial bonding between rebar and matrix results in a more durable structure. In addition, the use of GFRP instead of conventional steel reinforcement in structural elements increases elastic loading and unloading and allows for a compatible composite deformation behavior due to the lower stiffness of the GFRP reinforced ECC composite. Furthermore, the corrosion resistance of GFRP together with the limited crack widths of ECC results in improved corrosion resistance of the link slabs. As a result the ECC link slab can be used as a alternative to conventional mechanical expansion joints in viaduct and bridge structures.